SNe feedback and the formation of elliptical galaxies

Antonio Pipino[*] and Francesca Matteucci[*]

[*]*Dipartimento di Astronomia, Università di Trieste*

Abstract. The processes governing both the formation and evolution of elliptical galaxies are discussed by means of a new multi-zone photo-chemical evolution model for elliptical galaxies, taking into account detailed nucleosynthetic yields, feedback from supernovae, Pop III stars and an initial infall episode.

By comparing model predictions with observations, we derive a picture of galaxy formation in which the higher is the mass of the galaxy, the shorter are the infall and the star formation timescales. In particular, by means of our model, we are able to reproduce the overabundance of Mg relative to Fe, observed in the nuclei of bright ellipticals, and its increase with galactic mass.

This is a clear sign of an anti-hierarchical formation process. Therefore, in this scenario, the most massive objects are older than the less massive ones, in the sense that larger galaxies stop forming stars at earlier times.

Each galaxy is created outside-in, i.e. the outermost regions accrete gas, form stars and develop a galactic wind very quickly, compared to the central core in which the star formation can last up to ~ 1.3 Gyr. This finding will be discussed at the light of recent observations of the galaxy NGC 4697 which clearly show a strong radial gradient in the mean stellar $[<Mg/Fe>]$ ratio.

The role of galactic winds in the IGM/ICM enrichment will also be discussed.

INTRODUCTION

Any model of galaxy evolution presented so far had to overcome the strong challenge represented by the observational fact that elliptical galaxies show a remarkable uniformity in their photometric and chemical properties. Metallicity gradients are characteristic of the stellar populations inside elliptical galaxies. Evidences come from the increase of line-strength indices and the reddening of the colours towards the centre of the galaxies (for details and references see Pipino & Matteucci 2004, PM04). The study of such gradients provide insights into the mechanism of galaxy formation, particularly on the duration of the chemical enrichment process at each radius. Metallicity indices, in fact, contain information on the chemical composition and the age of the single stellar populations (SSP) inhabiting a given galactic zone. In particular, by comparing indices related mainly to Mg to others representative of the Fe abundance, it is possible to derive the [Mg/Fe] abundance ratio, which is a very strong constraint for the formation timescale of a galaxy. In fact, the common interpretation of the α-element (O, Mg, Ca, Si) overabundance relative to Fe, and its decrease with increasing metallicity in the solar neighbourhood is due to the different origin of these elements (time-delay model, Matteucci & Greggio, 1986), being the former promptly released by type II supernovae (SNII) and the latter mainly produced by type Ia supernovae (SNIa) on longer timescales. The time-delay model applies also to other objects and the $[\alpha/Fe]$ versus [Fe/H] relation

depends strongly on the star formation history. For a very short and intense star burst, the [α/Fe] ratios decrease at higher metallicity than in the solar vicinity. PM04 showed that a galaxy formation process in which the most massive objects form faster and more efficiently than the less massive ones can explain the photo-chemical properties of ellipticals, in particular the increase of [Mg/Fe] ratio in stars with galactic mass (see PM04). Moreover, from an extended analysis of metallicity and colour gradients, Pipino, Matteucci & Chiappini (2006, PMC) suggest that a single galaxy should form outside-in, namely the outermost regions form earlier and faster with respect to the central parts. A natural consequence of this model and of the time-delay between the production of Fe and that of Mg is that the mean [Mg/Fe] abundance ratio in the stars should increase with radius.

THE MODEL

The adopted chemical evolution model is based on that presented by PM04. In this particular case we consider our model galaxies as a multi-zone extending out to 10 effective radii, with instantaneous mixing of gas. Moreover we take explicitly into account a possible mass flow due to the galactic wind and a possible secondary episode of gas accretion in order to model late time gas accretion and/or interactions with the environment. The chemical code features a new self-consistent energy treatment which supersedes the previous one adopted by PM04 (see Pipino et al., 2005). Particular care is dedicated to a detailed calculations of Type Ia and II SN rates. The minimum SN efficiency required to develop a galactic wind is 10%.

RESULTS AND CONCLUSIONS

We find that SF and infall timescales decreasing with galactic mass are needed to explain the optical properties of elliptical galaxies (PM04). At the same time we reproduce the $L_X - L_B$ relation in the ISM of bright ellipticals (Pipino et al., 2005). Our best model satisfies the main constraint represented by the observed $[< \alpha/\text{Fe} >_\text{V}] - \sigma$ relation (see Fig. 1, left panel).

In Fig. 1 (right panel) we show the predicted radial trends of both the $[< \text{Mg}/\text{Fe} >]$ (solid line) and $[< \text{Mg}/\text{Fe} >_\text{V}]$ (dotted line) abundance ratios versus the *observed* one in NGC 4697. The latter is obtained by Mendez et al. (2005) by converting the line-strength indices into abundances. The agreement is remarkable, especially because we did not tune the input parameters (i.e. radius, mass) to exactly match NGC 4697. The observed increase of [Mg/Fe] with radius confirm PM04's model predictions, namely an outside-in formation process in which the central part of the galaxy form stars for a longer period compared to the most external regions. This can be explained in terms of galactic winds developing earlier where the local potential well is shallower.

By comparing the radial trend of $[< \text{Z}/\text{H} >]$ with the *observed* one, we notice a discrepancy which is due to the fact that a CSP behaves in a different way with respect to a SSP. In particular the predicted gradient of $[< \text{Z}/\text{H} >]$ is flatter than the observed
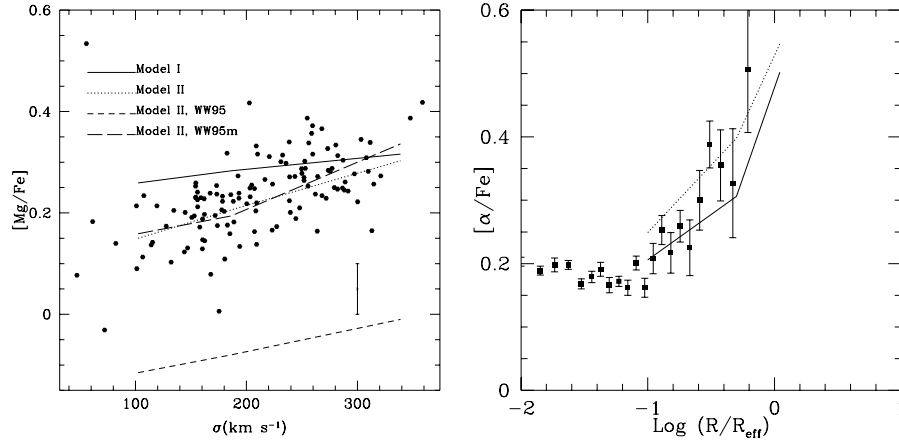
FIGURE 1. *Left:* [Mg/Fe] as a function of galactic velocity dispersion predicted by Model I (solid) and II (dotted) compared to the data from Thomas, Maraston, & Bender (2002). The typical error is shown in the bottom-right corner. For comparison we show the theoretical curves obtained with the same input parameters of Model II, but different yields (see text). WW95: yields by Woosley & Weaver (1995). WW95m: modified yields by Woosley & Weaver (1995), see PM04. *Right:* PM04's model IIb predictions for the mean mass-weighted $[< \alpha/Fe >]$ (solid) and luminosity-weighted $[< \alpha/Fe >_V]$ (dotted) abundance ratios in stars as a function of radius compared to the $[\alpha/Fe]$ derived for the galaxy NGC 4697 (Mendez et al. 2005, full squares).

one at large radii. Therefore, this should be taken into account when estimates for the metallicity of a galaxy are derived from the simple comparison between the observed line-strength index and the prediction for a SSP, a method currently adopted in the literature (see PMC).

The new energy formalism implemented in the chemical evolution code allows us to follow in a more detailed way the evolution of mass and energy flow into the ICM with respect to previous works. The predicted amount of Fe ejected by ellipticals into the ICM match the observations, and new data on the $[\alpha/Fe]$ ratios are in better agreement with our results (Pipino et al., 2005). Therefore, we confirm that SNe Ia are fundamental in providing energy and iron to the ICM.

ACKNOWLEDGMENTS

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